25 Years of national trisonic aerodynamic facilities (NTAF)

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Introduction

The Complex of National Trisonic Aerodynamic Facilities (NTAF) of National Aerospace Laboratories (NAL), set up under the auspices of the Council of Scientific & Industrial Research (CSIR) in 1967, celebrated its silver jubilee in the month of June 1993. NTAF now has a 1.2 m trisonic wind tunnel, 0.6 m transonic wind tunnel with the associated infrastructure such as compressed air facilities, electrical substation, design & drawing office, model shop, etc. During this period of 25 years, NTAF has developed a variety of sophisticated test techniques that have won for it a crucial role in the generation of aerodynamic design data for all the national aerospace projects in the country. Together with the significant improvements made over the years in productivity and the technical quality of the data generated, NTAF has developed into a major high speed testing centre comparable to the best elsewhere in the world. Furthermore, NTAF has become internationally very competitive in terms of time and cost for undertaking wind tunnel testing including design and fabrication of models and balances.

The following are the significant contributions of NTAF in the last 25 years.

- Development of comprehensive aerodynamic testing capabilities and services.
- Indigenous design and fabrication of complete high speed wind tunnel systems including control systems, models, balances and associated accessories.
- Generation of aerodynamic data on various flight vehicles, including satellite launch vehicles, missiles and fighter aircraft configurations, for national agencies such as Indian Space Research Organisation (ISRO), Defence Research & Development Organization (DRDO) and Hindustan Aeronautics Limited (HAL).

The paper emphasizes only some of the important test techniques developed and typical test results.

Aerodynamic data generation

A variety of aerodynamic measurements on different types of models have been made in support of various major aerospace projects in the country. These measurements have

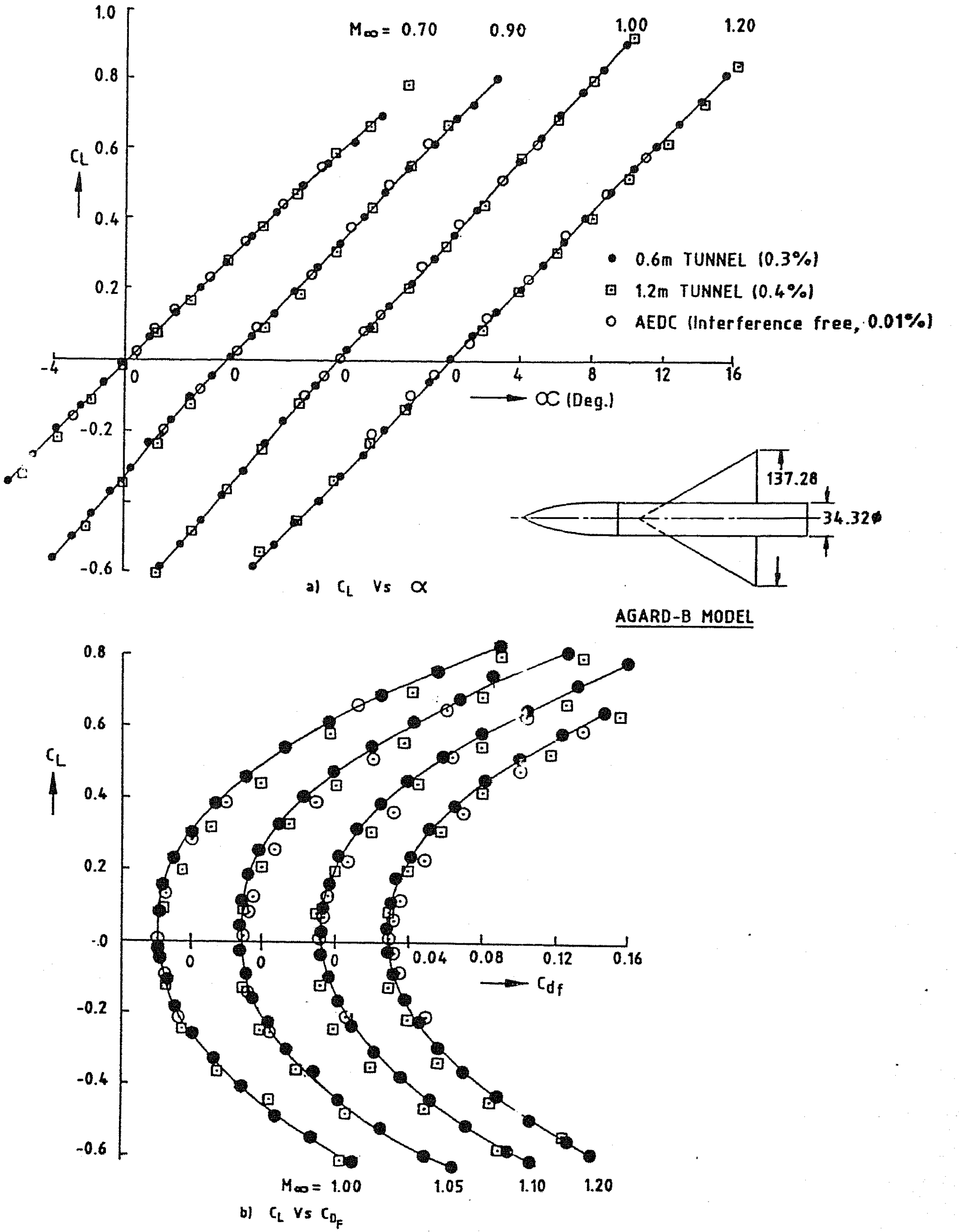


Figure 1. Comparison of force measurements on AGARD-B.

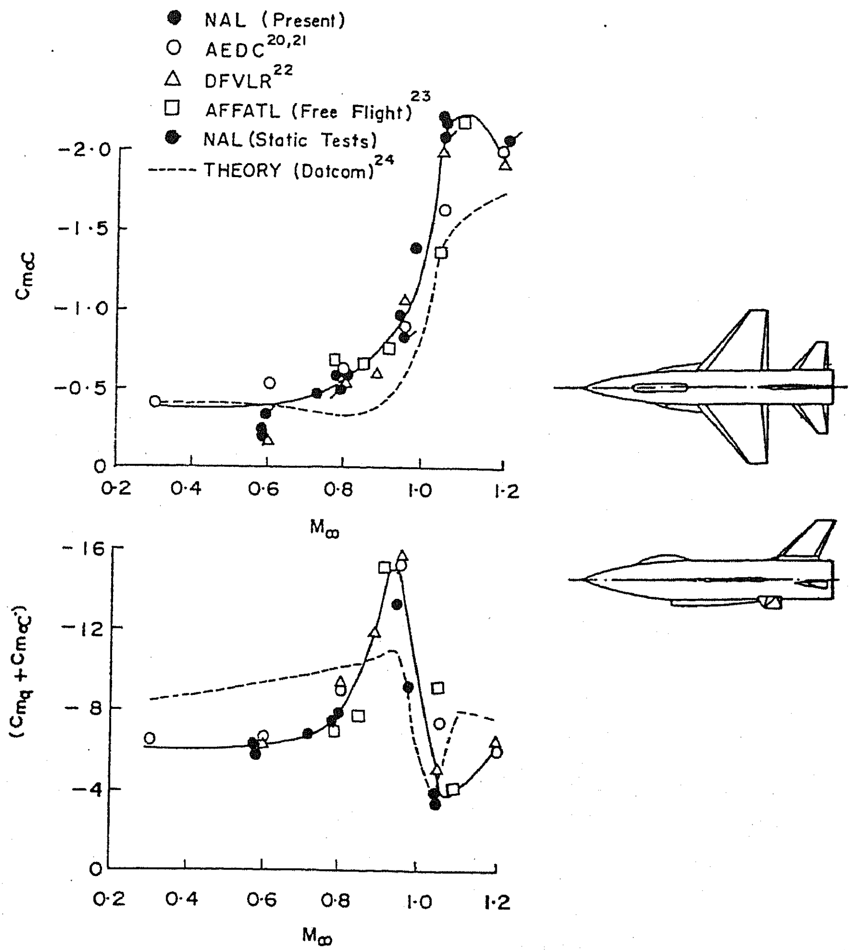


Figure 2. Comparison of pitch-oscillation results on SDM, $\alpha = 0$.

provided aerodynamic design inputs essential for the indigenous development of a variety of flight vehicles such as satellite launch vehicles, fighter and trainer aircraft, missiles, etc. Besides generating design data, tests conducted in high speed tunnels at NTAF have often provided valuable insight in understanding complex flow phenomena and aided the development of optimum configuration of flight vehicles.

The 1.2 m tunnel has completed a total of nearly 20,000 blowdowns so far. The quality of data obtained at NTAF compares favourably with that of other major aerodynamic testing facilities in the world. Figure 1 shows a typical comparison of data

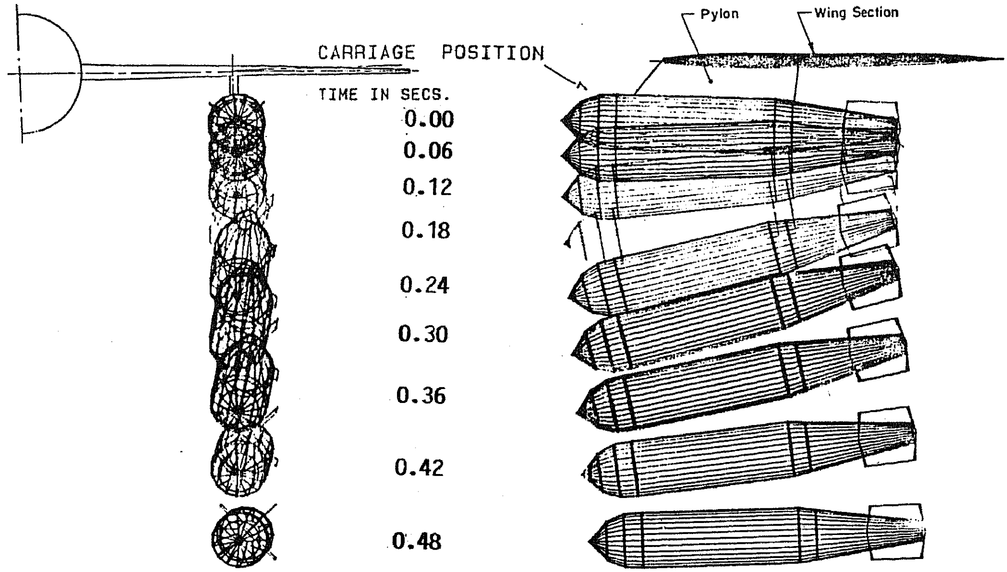


Figure 3. Post-processed store trajectory data from CTS.

obtained in the NAL 1.2 m and 0.6 m tunnels with similar data from other facilities abroad. Improvements made in instrumentation, data acquisition and processing systems have significantly enhanced the data throughput of the tunnel. For example, the number of data points per polar has risen from 10 to 100 in the last two decades. Presently NTAF is generating a total of 1,20,000 data points per year.

Development of advanced test techniques

To meet the special and wide ranging needs of aerospace organizations in the country, NTAF has been continuously upgrading its testing techniques and capabilities. Most of these techniques have been developed in-house and often necessitated innovative solutions to several challenging problems that arose due to difficulties associated with the small size of the tunnels (space constraints) and blowdown type of operation (short duration and high loads). While the semi-captive trajectory technique and its extension to multiple booster separation trajectory studies have been developed at NAL for the first time, flutter and dynamic stability and heat transfer measurements and aeroelastic tests which are carried out only in continuous tunnels abroad, have been successfully conducted in a blowdown tunnel at NAL. A brief description of some of these special test techniques follows.

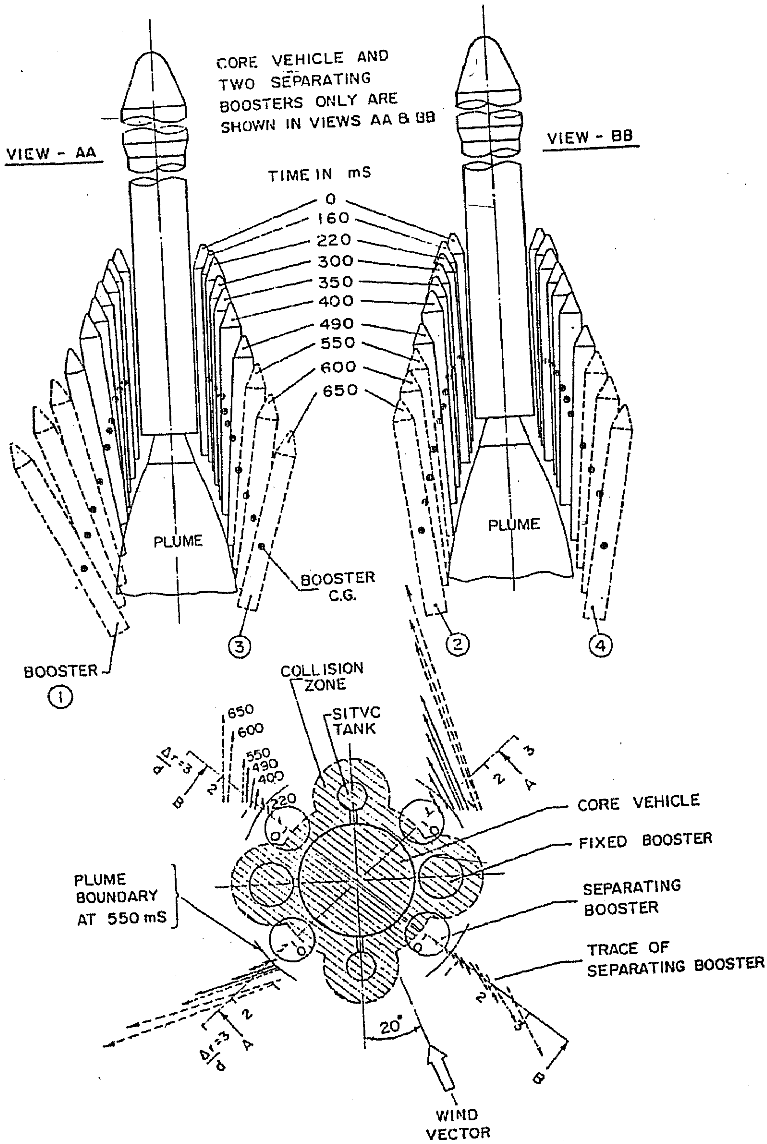
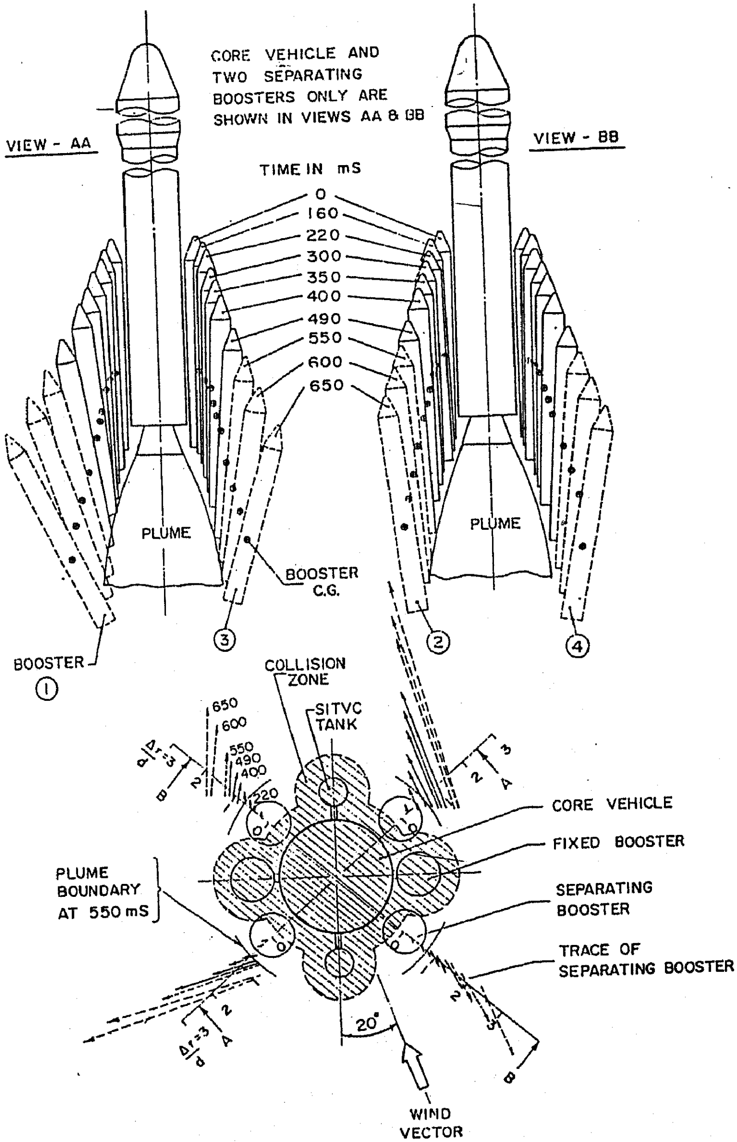


Figure 4. Schematic representation of separation trajectories. $\phi_w = 20°$.

Measurement of dynamic stability derivatives

A single-degree-of-freedom forced oscillation rig has been developed for measurement of dynamic stability derivatives. The rig features an electrodynamic shaker to oscillate the



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model at the desired frequency and amplitude about a crossed flexure pivot. The rig is instrumented to measure the exciting moment and the angular displacement of the model and is capable of measuring pitch and yaw damping derivatives of aircraft and missile configuration at angles of attack upto 20°. A typical result on standard dynamic model along with comparison of data from other tunnels is shown in Figure 2.

Semi-captive and fully captive trajectory simulation techniques for determining trajectories of a separating store from aircraft

The semi-captive trajectory simulation method developed at NAL has been extensively used for determining trajectories of separating stores from aircraft and single or multiple boosters from launch vehicles. The procedure consists of first measuring the aerodynamic forces acting on the store (or booster) model in its carriage position. The measured boosters from launch vehicles. The procedure consists of first measuring the aerodynamic forces acting on the store (or booster) model in its carriage position. The measured

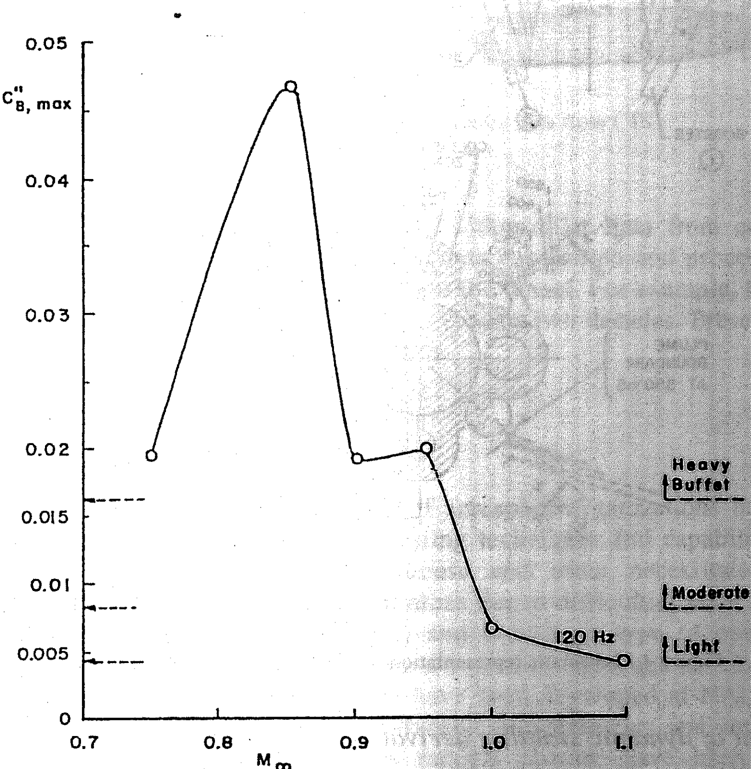
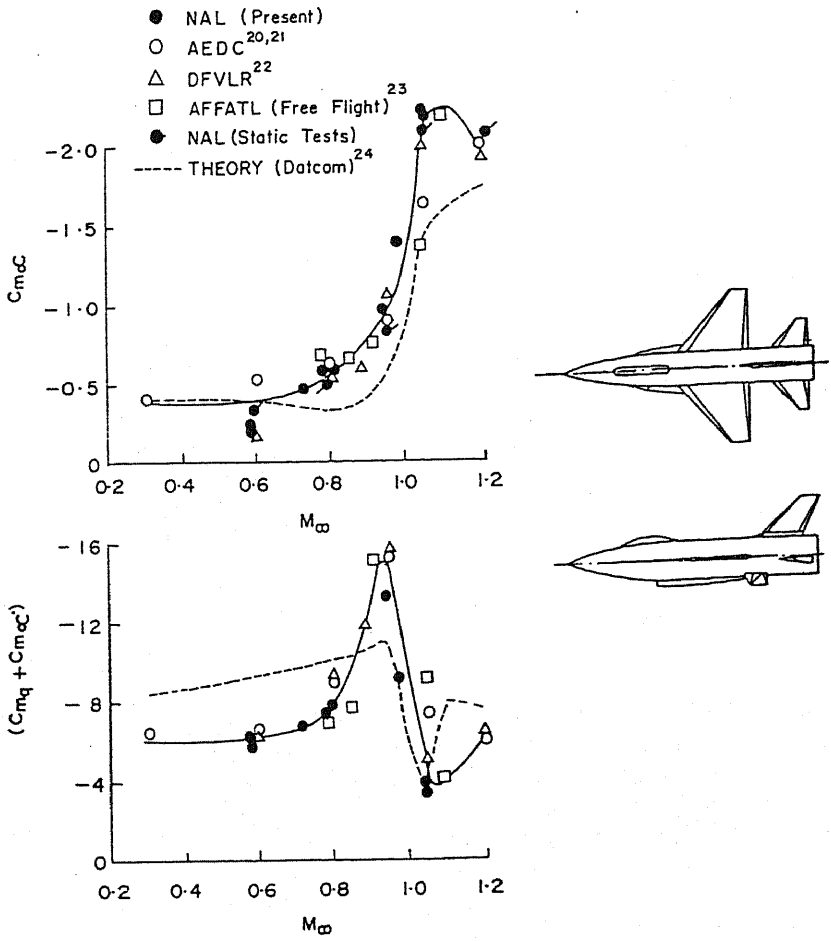


Figure 5. Variations of maximum buffeting coefficients with the Mach number.



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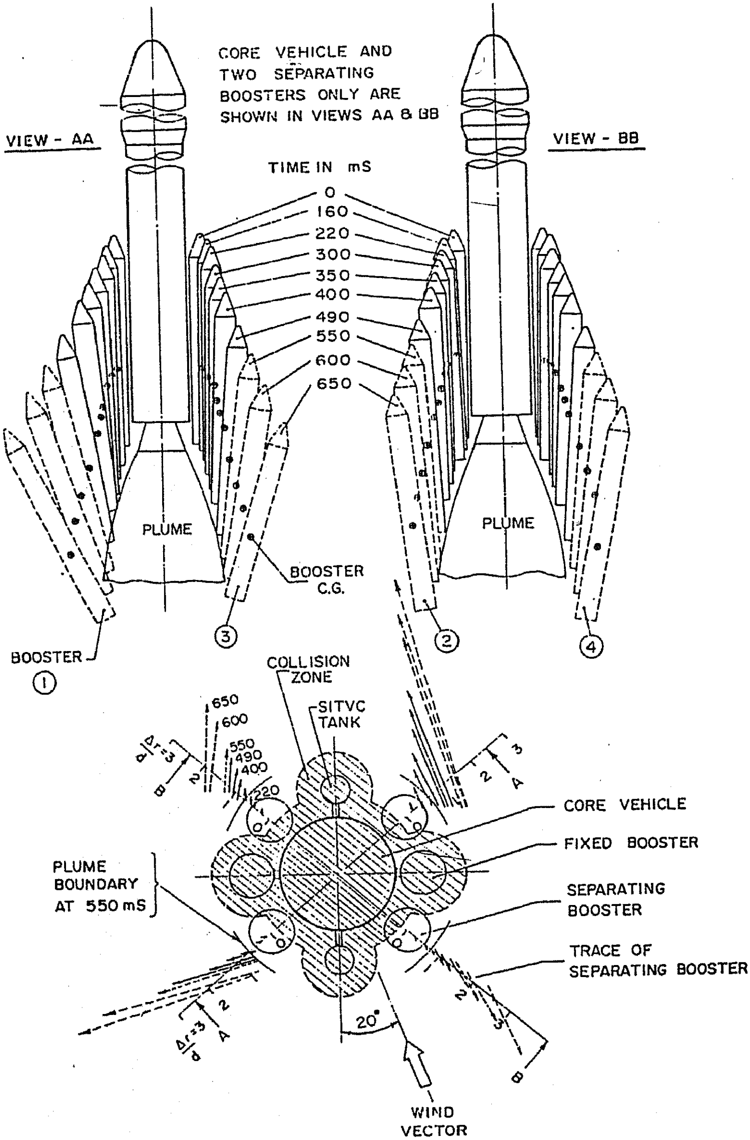

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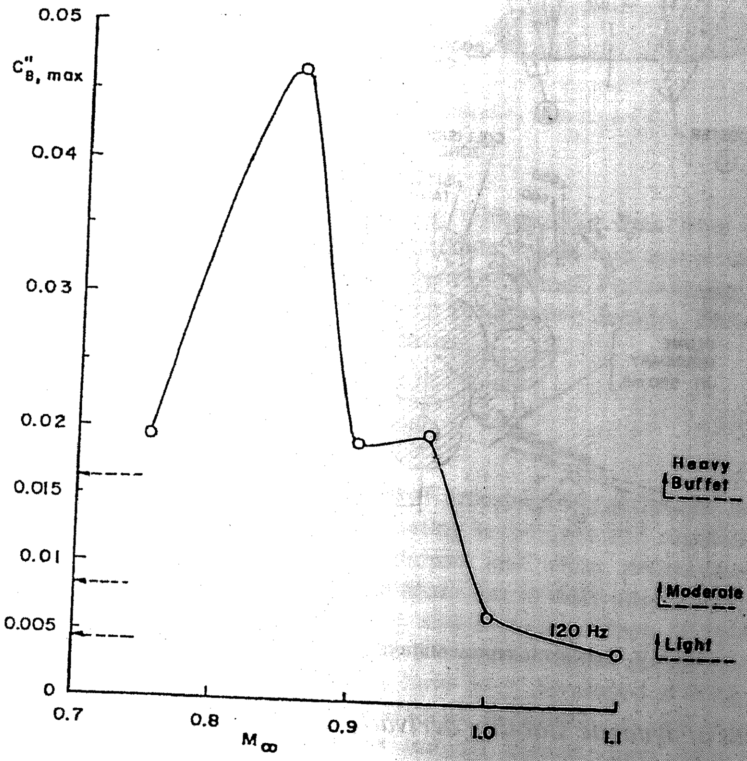


Figure 5. Variations of maximum buffeting coefficients with the Mach number.

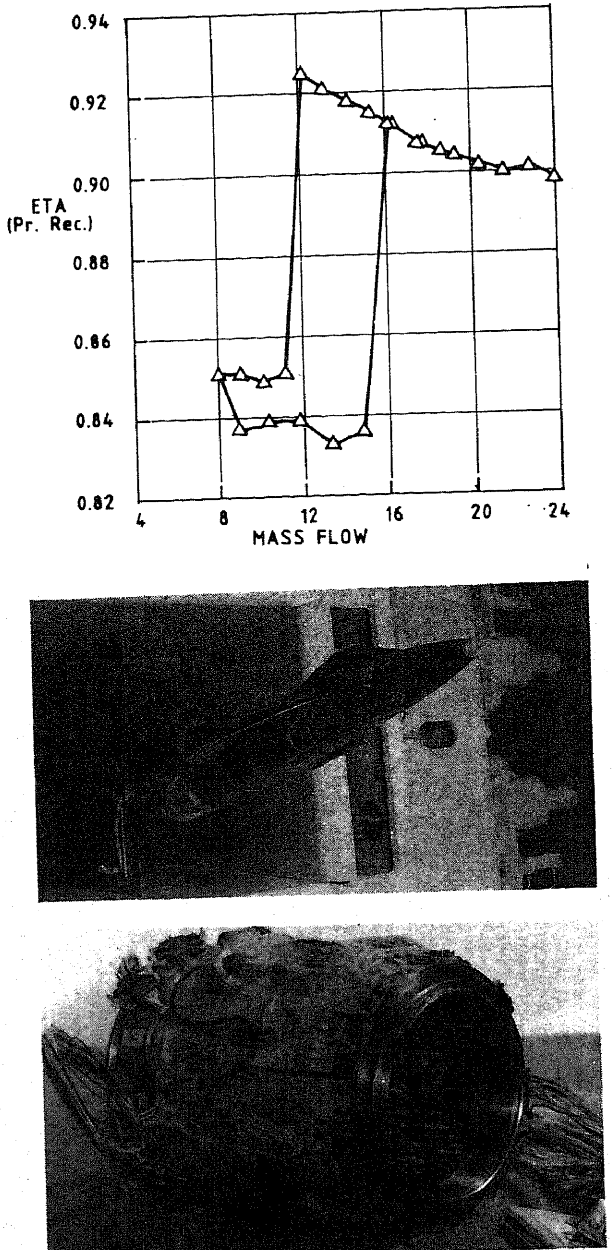
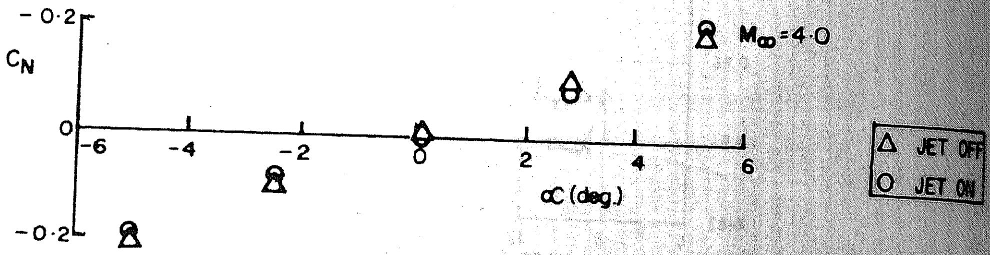


Figure 6. Effect of mass flow on pressure recovery of air intake.

aerodynamic data along with store (or booster) mass properties and ejection force are utilized to solve the equations of motion to obtain the position and attitude of the store (or booster) after a small time interval. The store is then manually set at the new position and attitude. The procedure is repeated till the trajectory is obtained in the region of interest. A fully captive trajectory system (CTS), which is a sophisticated computer-controlled electromechanical system for wind tunnel simulation of the trajectory of a store released from a parent aircraft, is also available with NTAF. DC servomotors housed in the auxiliary support rig provide store movement with six degrees of freedom. Each of the six



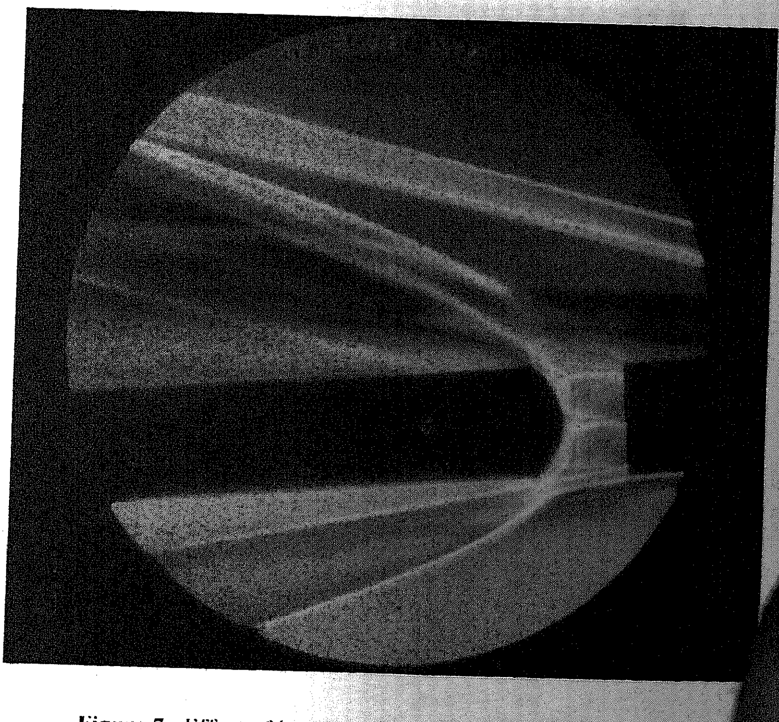


Figure 7. Effect of jet on normal force characteristics of stage 1.

motors along with a direct coupled tacho generator is connected in a closed loop servo and controlled by a Micro VAX-II computer to automatically drive the model to the computed position and attitude. A typical post-processed data of a store separating from aircraft is shown in Figure 3.

Determination of multi-booster separation trajectories of launch vehicles

The semi-captive trajectory technique has been extended to enable determination of multi-booster separation trajectories of launch vehicles. An elaborate test set up was specially designed and built to conduct these tests. The special rig features four independent six-degree-of-freedom articulated support mechanisms and four strain gauge balances. The rig has been successfully utilised to investigate the separation characteristics of strapon boosters separating simultaneously from the core of the launch vehicles at high supersonic speeds. It is believed that tests of such complex nature involving four simultaneously separating boosters have been successfully conducted for the first time in the world. A typical data of four strap-on boosters separating from a launch vehicle is shown in Figure 4.

Component load measurements of aircraft and launch vehicles

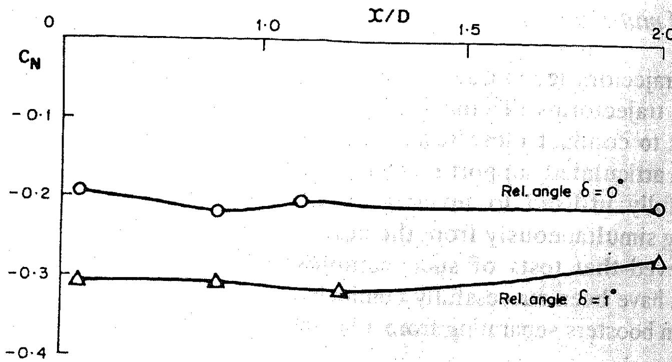
While conventional force measurements on flight vehicle models give vital aerodynamic design data for performance studies, component loads are essential for structural design and to establish performance limits. Aircraft component loads such as on wing and fin have been successfully measured through specially designed balances. Besides measuring the total loads on missiles and launch vehicle models, auxiliary balances have also been used to simultaneously measure the loads on components like canard, fin, strap-on boosters, nose petals, etc.

Heat transfer measurements on the nose cone of a launch vehicle

Knowledge of surface heat transfer rates on the nose cone of a satellite launch vehicle is essential for designing a suitable heat shield to avoid excessive temperatures in payload bay. A thin-skin calorimeter technique has been developed at NAL and employed to measure heat transfer rates in simulated flow conditions in the wind tunnel. The model is pre-cooled by filling liquid nitrogen in the enclosure formed by two segments of a thermally insulated metal shroud. The segments are retracted as soon as tunnel flow is established and the subsequent temperature history of the thin skin is monitored for deriving the heat transfer rates.

Full-scale flutter measurement on launch vehicle fins

Flutter refers to dynamic aeroelastic instability involving interaction between aerodynamic, elastic and inertia forces. The onset of flutter is determined by testing an aeroelastically scaled strain-gauged model under increasing dynamic pressure levels and observing the diverging trend in the fluctuation levels of strain gauge output signals. Retractable shrouds are used for protecting the model from high transient loads that occur during initiation and termination of a blowdown.



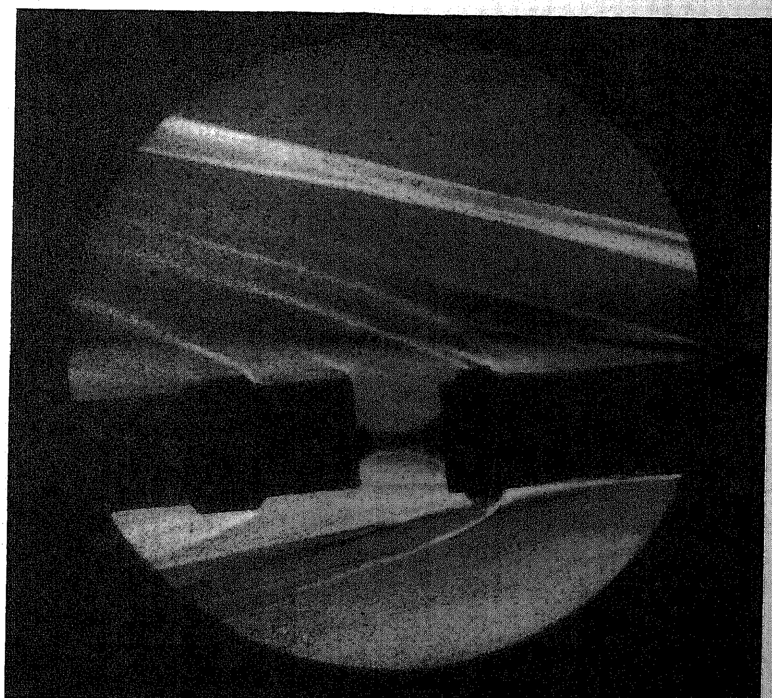


Figure 8. Effect of stage 2 on stage 1 aerodynamics at $\alpha = 5°$.

Aeroelastic tests on launch vehicles

Aeroelastic models of satellite launch vehicles (simulating the stiffness of the vehicles as well) have been successfully tested at critical dynamic pressures to detect occurrence of any divergence phenomenon. Proximity plates have been effectively employed to protect the models from large aerodynamic loads that occur during starting and stopping of a blowdown tunnel.

Buffet studies on aircraft and launch vehicles

Buffeting is the undesirable vibration of an aircraft structure caused by flow separation phenomena on parts of the wing. A number of standard wind tunnel test techniques have been adapted at NAL to indicate buffet onset and measure buffet intensity. Buffet onset is

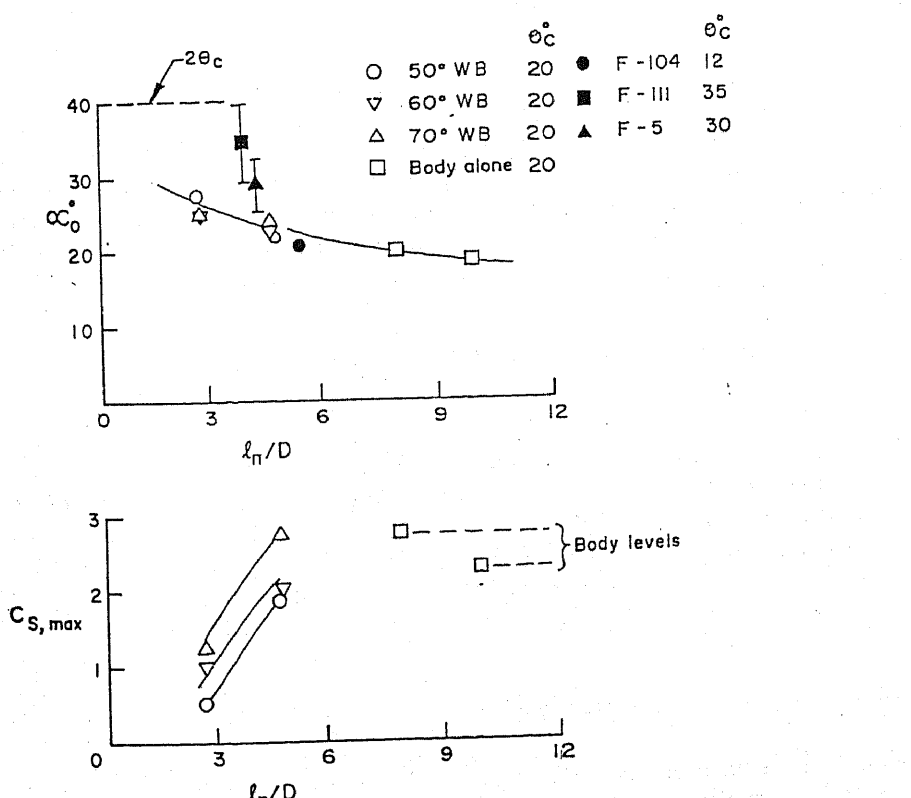


Figure 9. Effect of nose fineness ratio on the onset of vortex asymmetry and maximum side force magnitudes.

determined by the divergence of mean trailing edge pressure, abrupt rise in fluctuation levels of wing root strain and abrupt changes in mean aerodynamic forces. Buffet intensity is estimated by means of high-response flush-mounted pressure transducers, wing root strain gauges and wing tip mounted accelerometers. A typical data on an aircraft configuration is shown in Figure 5.

Air intake measurements

Study of performance of air intakes of aircraft configuration requires large-scale models extensively instrumented with Kulite probes at compressor face. The studies made in the 1.2 m tunnel emphasized measurement of pressure recovery, distortion and buzz characteristics. A typical result on an aircraft model at $M = 1.5$ is shown in Figure 6.

Stage separation studies

A special purpose rig has been developed to enable simulation of cold jet from the ongoing stage while the jettisoned stage is still in the vicinity. Force measurements are made on the jettisoned stage (stage 1) in the presence of jet. A typical result shown in Figure 7 illustrates that the impinging jet has insignificant effect on the normal force characteristics of stage 1. A typical result of a similar study with the jet off is shown in Figure 8. The variation of normal force characteristics of stage 1 with certain misalignment of stage 1 with respect to stage 2 is shown.

Aerodynamic characteristics of delta-wing body combination at high angles of attack

A systematic study was undertaken recently in the 1.2 m tunnel to provide a broad understanding of the nose-induced vortex flows at high incidence on relatively simpler wing-body combinations. The study addressed the effects of vortex asymmetry on the gross wing-body aerodynamic characteristics and also provided a good data base for use in the development of engineering calculation methods at high incidence as well as for validating CFD codes. A typical result is shown in Figure 9.

Unsteady pressure measurements

Models instrumented with flush mounted Kulite transducers are tested to measure the spectra and rms levels of surface pressure fluctuations. A typical result showing the effect of a 3D protrusion on the pressure fluctuation levels on an axisymmetric body is shown in Figure 10.

Design and fabrication

Over the years, NTAF has built in-house capacity to design and fabricate complex models, internal strain gauge balances and other hardware required for high speed wind

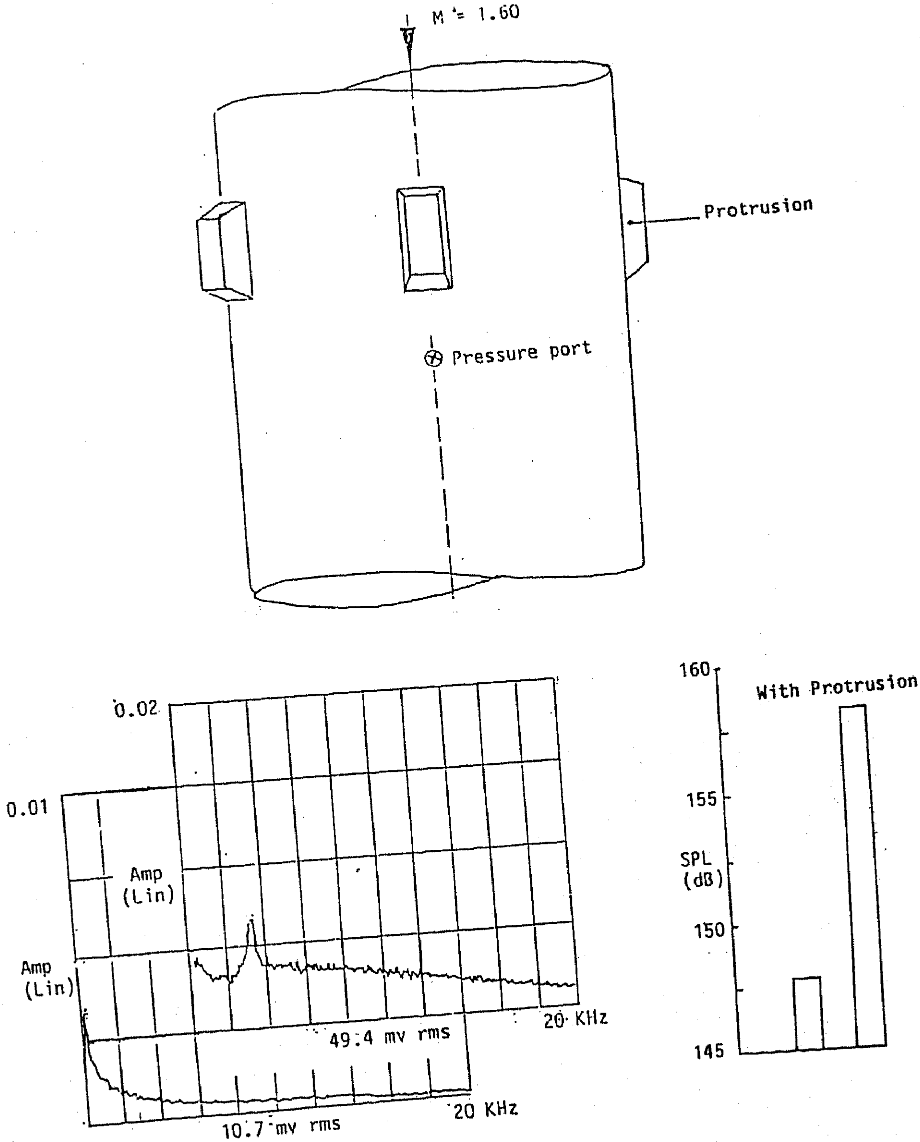


Figure 10. Effect of protrusions on pressure fluctuations on an axisymmetric body.

tunnel testing using CNC and other advanced technology. This capability has enabled us to be internationally competitive in terms of time and cost in design and fabrication of models and balances, saving considerable foreign exchange for the country every year. To meet the increasing demands of the users in recent times, NTAF has developed the capabilities of other vendors in the country who can now undertake the intricate fabrication work of complex wind tunnel models and balances.

NTAF has also built up proven ability to design, fabricate, erect and commission high speed wind tunnels and associated systems. The 0.6 m transonic tunnel commissioned at NAL in 1989 is a typical example. This tunnel was built mainly to off-load the 1.2 m tunnel in the transonic region and also to facilitate more R&D investigations. The tunnel features state-of-art computer-based controls and data acquisition system.